Ediacaran–Palaeozoic tectonic evolution of the Ossa Morena and Central Iberian zones (SW Iberia) as revealed by Sm–Nd isotope systematics

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A B S T R A C T

Sm–Nd isotopic analyses of Palaeozoic sedimentary and igneous rocks in the southwest Iberian Massif (western end of the European Variscan Belt) are presented in order to unravel its complex poly-orogenic evolution during the closure of the Rheic Ocean and the amalgamation of Pangea. The Gondwanan margin in southwest Iberia SW Iberia is subdivided into the Ossa Morena and Central Iberian zones, separated by the Badajoz–Córdoba Shear Zone which represents a cryptic suture zone between these terranes. The relat- ionships between these terranes, and between units preserved within the suture zone (e.g. the Sierra Albarrana Group) during the Palaeozoic and Neoproterozoic are controversial. Sm–Nd isotopic studies of representative sedimentary sequences covering the entire pre-Variscan record of the Ossa Morena and Central Iberian zones show very similar characteristics from the uppermost Ediacaran onwards. These data indicate that their accretion to one another must have been completed by the Late Neoproterozoic–Ediacarin that time (an event assigned to Cadomian orogeny) and that they never separated substantially from each other since that time. The Sm–Nd isotopic composition of the Sierra Albarrana Group metasedimentary rocks is similar to that of the pre-Cadomian sequences of the Ossa Morena Zone (Serie Negra), suggesting derivation from a common source. The common provenance of the Palaeozoic sequences in the two zones is identical to that of the pre-Cadomian Serie Negra of the Ossa Morena Zone, which in accordance with the data presented herein and published U–Pb zircon data indicates a West African affinity.

Keywords:
Tectonic evolution Ossa Morena Zone Central Iberian Zone Nd isotopes

1. Introduction

Reconstructing global palaeogeography is a complex task that requires a multi-disciplinary approach involving faunal, palaeomag- netic, lithotectonic, and geochemical as well as isotopic studies. Ancient orogenic belts located at former margins of palaeocontinents are particularly complex because they are prone to fragmentation and dispersal and accretion with other continental masses as a conse- quence of subsequent break-up and amalgamation processes. The Iberian Peninsula is dominated by the Iberian Massif, a composite continental block that was shaped by Late Palaeozoic Variscan tec- tonics during closure of the Rheic Ocean and the amalgamation of Pangea, followed by the Mesozoic opening of the fringing Tethys and Atlantic oceans during the break-up of Pangea (Bard et al., 1973; Matte and Ribeiro, 1975; Matte, 1986, 2001; Franke, 1989; Ribeiro et al., 1990; Quesada et al., 1991; Quesada, 1991, 2006; Pereira and Quesada, 2006).

The original relationship between the OMZ and CIZ is fundamental to the understanding of the evolution of the Iberian Massif, Variscan tectonics and Pangea amalgamation. As noted by Soper and Woodcock (1990), palaeomagnetic and faunal data commonly do not have the precision to constrain these relationships, especially in situations where terrane boundaries have had complex evolutions in which post- accretionary movements may have masked earlier histories. Another approach to constraining the docking of terranes is the identification of oldest sedimentary strata that overstep the terrane boundary. In complex areas, petrographic and geochemical studies, by themselves, cannot distinguish between potential continental sources of clastic rocks. Sm–Nd isotopic studies of clastic rocks, however, provide constraints on the weighted average of the contributions from each source area (e.g. Thorogood, 1990). As Sm and Nd are concentrated in heavy minerals, sedimentary processes such as fractionation or accumulation of heavy minerals during sediment transport, may exert a dominant control, whereas the source of silicate phases is less constrained.

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Sm–Nd isotope analyses of igneous rocks can identify the relat- ive influences of crustal and mantle-derived constituents and reveal crustal formation from the mantle at given times (Armstrong, 1968; Hofmann and White, 1980; DePaolo, 1983; White and Patchett, 1984, Murphy and Nance, 2002).

In this paper we present 47 Sm–Nd isotope analyses from meta-sedimentary (37) and metaigneous (10) rocks covering most of the stratigraphic record of the CIZ, the OMZ and the intervening Badajoz– Córdoba Shear Zone in the SW Iberian Massif. We characterize and compare their respective sources from Ediacarin to the Early Devonian time, and investigate the timing of their juxtaposition within the context of the tectonic evolution of the evolution of the Iapetus and the Rheic oceans and the northern Gondwanan margin. Sm–Nd isotopic data for Variscan syn-orogenic times (Late Devonian– Carboniferous), are described and interpreted in a companion paper (Armendáriz et al., 2008-this volume).

2. Geological setting

The Iberian Massif exposes the largest piece of the European Variscan Orogen (Lotze, 1945) and preserves several Ediacaran and Palaeozoic continental crustal blocks as well as oceanic complexes which have been interpreted to represent sutures among them (Ribeiro et al., 1990; Quesada, 1991; Martínez Catalán et al., 1997; Díaz García et al., 1999; Simancas et al., 2002; Pin et al., 2002; Arenas et al., 2007a,b,c). Tectonostratigraphic zones have been defined within the Iberian Massif on the basis of the differences in stratigraphy, structure, magmatism and metamorphic evolution (Lotze, 1945; Julivert et al., 1974; Farias et al., 1987; Quesada, 1991) (Fig. 1). The southernmost zone (South Portuguese Zone, SPZ) is considered an exotic terrane of Laurussian (Avalonian) affinity that is separated from the peri-Gondwanan Ossa Morena Zone (OMZ) by the oceanic Pulo do Lobo (PDL) terrane and the Beja-Acebuches ophiolite (BAO) (Andrade, 1979; Bard and Moine, 1979; Munhá et al., 1986; Eden and Andrews, 1990; Quesada, 1991; Eden, 1992; Quesada et al., 1994, 2006). The PDL and BAO are oceanic units inter- preted as vestiges of the Rheic Ocean (Robardet et al., 1993; Simancas et al., 2002; Quesada et al., 2006) and collectively define a Variscan suture within the Iberian Massif. The relationship of the PDL and BAO with the other alleged Rheic Ocean suture related ophiolites in the NW Iberia allochthonous complexes (Arenas, 2007a,b,c; Martinez-Catalan, 2004) has not yet been clearly established. To the north of the Rheic suture, the OMZ is in tectonic contact with the Central Iberian Zone (CIZ) through a wide and structurally complex shear belt known regionally as the Badajoz–Córdoba Shear Zone (Fig. 1; Burg et al., 1981; Matte, 1986; Ábalos et al., 1991; Azor et al., 1994; Quesada and Dallmeyer, 1994). Both of these zones, as well as the rest of the so-called Iberian Autochthon (which also includes the West Asturian–Leonese and Cantabrian zones, Ribeiro et al., 1990; Quesada, 1991, Fig. 1), share a common peri- Gondwanan evolution throughout the Palaeozoic (e.g., Quesada, 1991; Robardet, 2003; Martínez Catalán et al., 1997, 2004, 2007). The presence of amphibolites with MORB-affinities and high-pressure metamorphic rocks suggest that this boundary is an oceanic suture between two continental blocks (Munhá et al., 1986; Ábalos, 1990; Quesada and Munhá, 1990; Quesada, 1990a,b, 1997; Gómez-Pugnaire et al., 2003). However, owing to very intense structural and metamorphic over- printing together with still scarce geochronologic data, the age of the amalgamation or suturing process is controversial. Three interpretations have been proposed: i) suturing took place in Variscan times (Azor et al., 1994, 1995; Azor, 1997; Simancas et al., 2001); ii) Ediacaran (Cadomian) suturing that was subsequently reactivated as a sinistral wrench fault zone during the Late Palaeozoic Variscan orogeny (Arthaud and Matte, 1977; Ábalos, 1990; Ábalos and Eguiluz, 1990; Quesada, 1990a,b, 1997; Quesada and Dallmeyer, 1994), iii) strike-slip accretion or docking of OMZ and CIZ as a consequence of along-margin terrane transport in

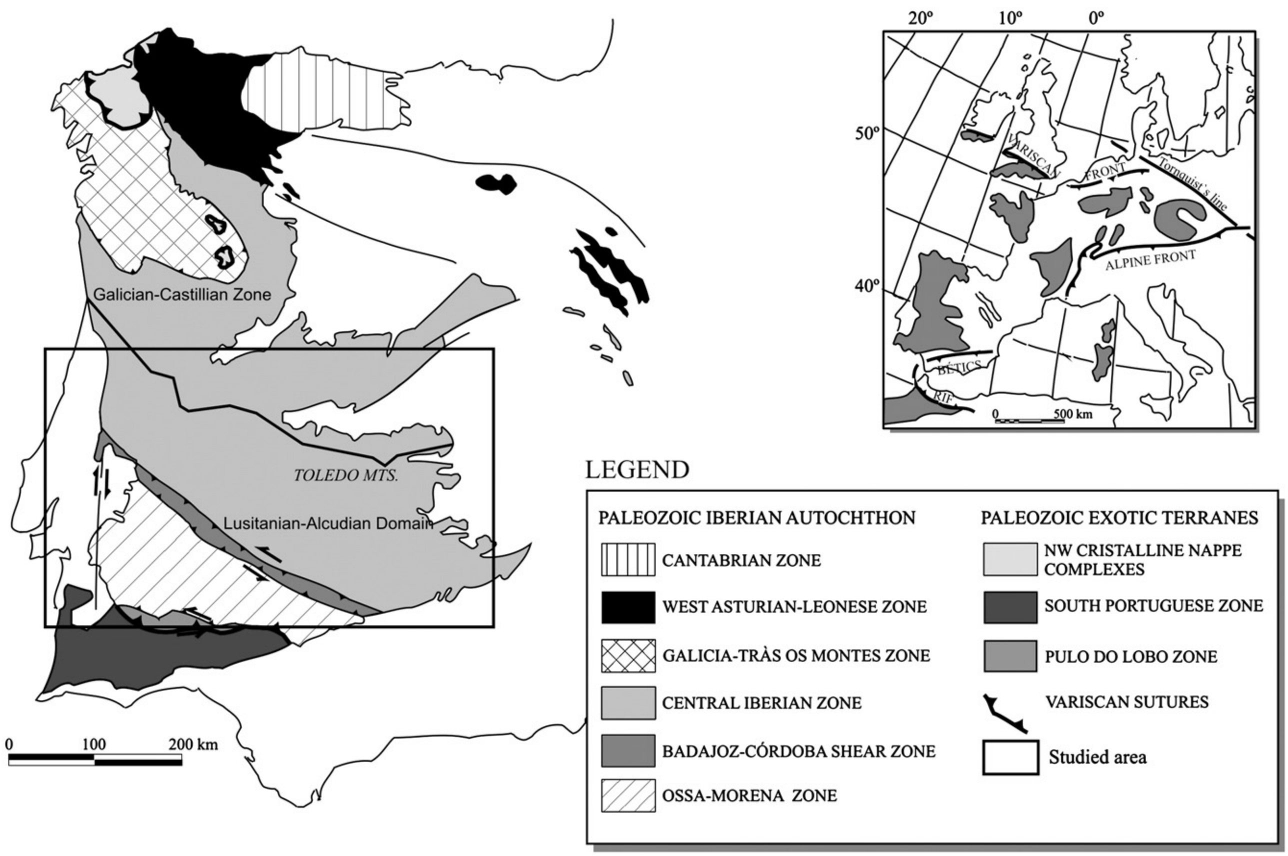

Fig. 1. Zonal division of the Iberian Massif (modified after Lotze, 1945; Julivert et al., 1974; Farias et al., 1987 and Quesada, 1991).

latest Ediacaran times that was reactivated during the Variscan orogeny (Fernández-Suárez et al., 2002a,b; Gutiérrez Alonso et al., 2003).

3. Comparative tectonostratigraphy

Prior to the onset of the Late Palaeozoic Variscan orogeny, the stra- tigraphy in both the OMZ and CIZ include Ediacaran and Palaeozoic rocks that are interpreted to record (Quesada, 1991; Quesada et al., 1991, 2006):

1) An Ediacaran–earliest Cambrian tectonic event associated to the Cadomian–Avalonian orogeny along the northern margin of Gondwana.
2) Sedimentary and igneous rocks deposited/emplaced during a Cam- brian–Early Ordovician rifting event (culminating in the opening of the Rheic Ocean),
3) Sedimentary strata deposited during the Ordovician–Devonian pas- sive margin development along the southern (Gondwanan) flank of the Rheic Ocean.

The main characteristics of the studied successions are summar- ized below.

3.1. The Ediacaran record (Cadomian–Avalonian orogeny)

The Ediacaran stratigraphic record exposed in the OMZ begins with pre-orogenic (pre-Cadomian) metasedimentary successions (Serie Negra; Alía, 1963), in which a lower, mature, black chert- bearing (Montemolín Formation; Eguiluz, 1987) is interpreted to record the sedimentation in a continental passive margin (Quesada, 1990a,b, 1997). It is overlain by a volcaniclastic–turbiditic succession (Tentudía Formation Eguiluz, 1987), interpreted as back-arc basin fill deposits (Quesada, 1990a,b, 1997). The transition between these two Ediacaran sequences is marked by an intervening package of tholeiitic basalts and dikes, which are interpreted to represent the rifting of the back-arc basin (Quesada, 1990a,b, 1997). The first event of Cadomian deformation is interpreted by Quesada (1997) to be related to the closure of the back-arc basin in the Ediacaran. In the OMZ, these rocks are unconformably overlain by a calc-alkaline, subduction-related volcanosedimentary syn-orogenic sequence and related plutonic rocks (Malcocinado Formation and correlatives; Fricke, 1941) that are inter- preted to reflect of the development of a volcanic arc on OMZ crust during southward-directed (present coordinates) subduction of the back-arc basin floor (Ábalos, 1990; Quesada, 1990a,b, 1997; Sánchez Carretero et al., 1991; Quesada et al., 2006). Closure of the back-arc resulted in accretion/collision of the OMZ arc to/with the margin of the CIZ part of Gondwana.

Further north, the Central Iberian Zone was defined by Julivert et al. (1974) by grouping together the former Galician–Castillian (*Ollo de Sapo Domain*) and East Lusitanian–Alcudian (*Schist and Graywacke Complex Domain*) zones of Lotze (1945) on the basis of their very similar Palaeozoic stratigraphy. We focus on the southern part of the Central Iberian Zone (the former East Lusitanian–Alcudian Zone of Lotze, 1945). The Neoproterozoic stratigraphic record in this area is limited to the so-called Schist and Graywacke Complex (Carrington da Costa, 1950; Vilas et al., 1987; Ortega Gironés et al., 1988; Ribeiro et al., 1991; Palero, 1993; Santamaría and Remacha, 1994; López Díaz, 1995; Rodríguez Alonso and Alonso Gavilán, 1995; Pieren, 2000; Valladares et al., 2000; Pieren and Herranz, 2000, 2001; Pereira and Silva, 2002; Rodríguez Alonso et al., 2004), which consists of two thick and unconformable pelite-graywacke sequences that are separated by an angular unconformity. Various interpretations have been given to the depositional environment of the Schist and Graywacke Complex, ranging from sedimentation on a passive margin (Ugidos et al., 1997, 2003; Valladares et al., 2000) to (Cadomian) syn-orogenic flysch on the footwall to the Cadomian suture with the OMZ, which is inter- preted to lie along the ancestral Badajoz–Córdoba Shear Zone (Fig. 1) (Quesada,1990a,b, 1997). The Upper and Lower sequences both con- tain interbedded debris flows, glaciomarine diamictites (Pieren Pidal, 2000) and minor calc-alkaline volcanic rocks (Rodríguez Alonso, 1985; Rodríguez Alonso and Alonso Gavilán, 1995; Pieren, 2000; Rodríguez Alonso et al., 2004). The Upper sequence reaches into the lowermost Cambrian and includes some carbonate and phosphate rocks (Ortega Gironés and González Lodeiro, 1986). The depositional age of the Schist and Graywacke Complex is interpreted to range from 600 to 540 Ma (Vidal et al., 1999). Both sequences are characterized by conglomerates that contain black chert cobbles which are thought to be derived from the Serie Negra metasedimentary succession of the OMZ (Rodríguez Alonso, 1985; Pieren Pidal, 2000). If correct, this interpretation implies a geographic linkage of the OMZ and CIZ at least since the Ediacaran.

Within the Badajoz–Córdoba Shear Zone (Fig. 1), there are units that exhibit the same Ediacaran stratigraphy that has been outlined above in the OMZ (Delgado, 1971; Apalategui et al., 1985). However, there are also some enigmatic units whose affinity and age are controversial due to their intense deformation, metamorphism and lack of fossil remains (other than sparse ichnofossils of uncertain significance interpreted by Marcos et al. (1991) as Ordovician in age. These ichnofossils mainly occur within the Sierra Albarrana domain (Delgado, 1971; Garrote, 1976; Delgado et al., 1977) that consists of (Fig. 2): i) a lower, Sierra Albarrana Group (Apalategui et al., 1985), made up of platformal metapelites and quartzites, and ii) an upper, turbiditic, Azuaga Formation (Delgado, 1971). Field relationships show that these sequences were deformed and metamorphosed prior to intrusion of Early Ordovician granites (c. 480 Ma; Priem et al., 1970; Lancelot et al., 1985; Oschner, 1993; Ordóñez, 1998). This relationship indicates that the deposition of the Sierra Albarrana Group predates deposition of the rift-to-drift sequences associated with opening of the Rheic Ocean, including the lithologically similar Armorican Quart- zite. As there is no independent evidence of deformation between the Cadomian orogeny and the onset of Rheic Ocean rifting, we follow (Garrote 1976, Delgado et al., 1977 and Quesada 1990a,b, 1997) in assuming an Ediacaran age for the Sierra Albarrana rocks.

All the Ediacaran sequences in the Ossa Morena, Central Iberian and the intervening Badajoz–Córdoba Shear Zone were variably deformed and metamorphosed during the Ediacaran–Earliest Cam- brian Cadomian orogeny that is interpreted to reflect the accretion of the OMZ arc to the adjacent CIZ block (Ábalos, 1990; Quesada, 1990a,b, 1997).

3.2. The Early Cambrian–Early Ordovician record (rifting stage)

In both the OMZ and the CIZ, orogenic activity and related coeval sedimentation and magmatism suddenly ceased in the Early Cam- brian. In both zones, pre-Cadomian rocks are overlain with angular unconformity (Sardic unconformity, Lotze, 1956) by a Middle Cam- brian to Early Ordovician rift-to-drift sequence of sedimentary and igneous rocks (Quesada, 1991; Quesada et al., 1991; Sánchez García et al., 2003, 2008-this volume; Expósito et al., 2003; Simancas et al., 2004; Quesada et al., 2006), thought to reflect a extensional regime which eventually culminated in the Early Ordovician by the opening of a new oceanic basin (Rheic Ocean) by the drift of a continental terrane (Avalonia?) away from the northern Gondwanan margin (Quesada, 1987, 1991; Sánchez García et al., 2003, 2008-this volume; Murphy et al., 2006; Quesada et al., 2006). Although they share a common history of platform sedimentation in variably subsiding horst and graben domains, the expression of this event is very different in the OMZ and the CIZ. In the OMZ, voluminous igneous activity occurred in two pulses (c. 530 Ma and c. 517–502 Ma, respectively; TIMS U–Pb zircon ages: Sánchez García et al., 2003, 2008-this volume; Quesada et al., 2006) indicating the location of the OMZ near the rift axis. In the CIZ, igneous activity associated with this event is very heterogeneous, and is very sparse in the southern part of the CIZ, in contrast to voluminous activity in the northern part of the CIZ around 470–

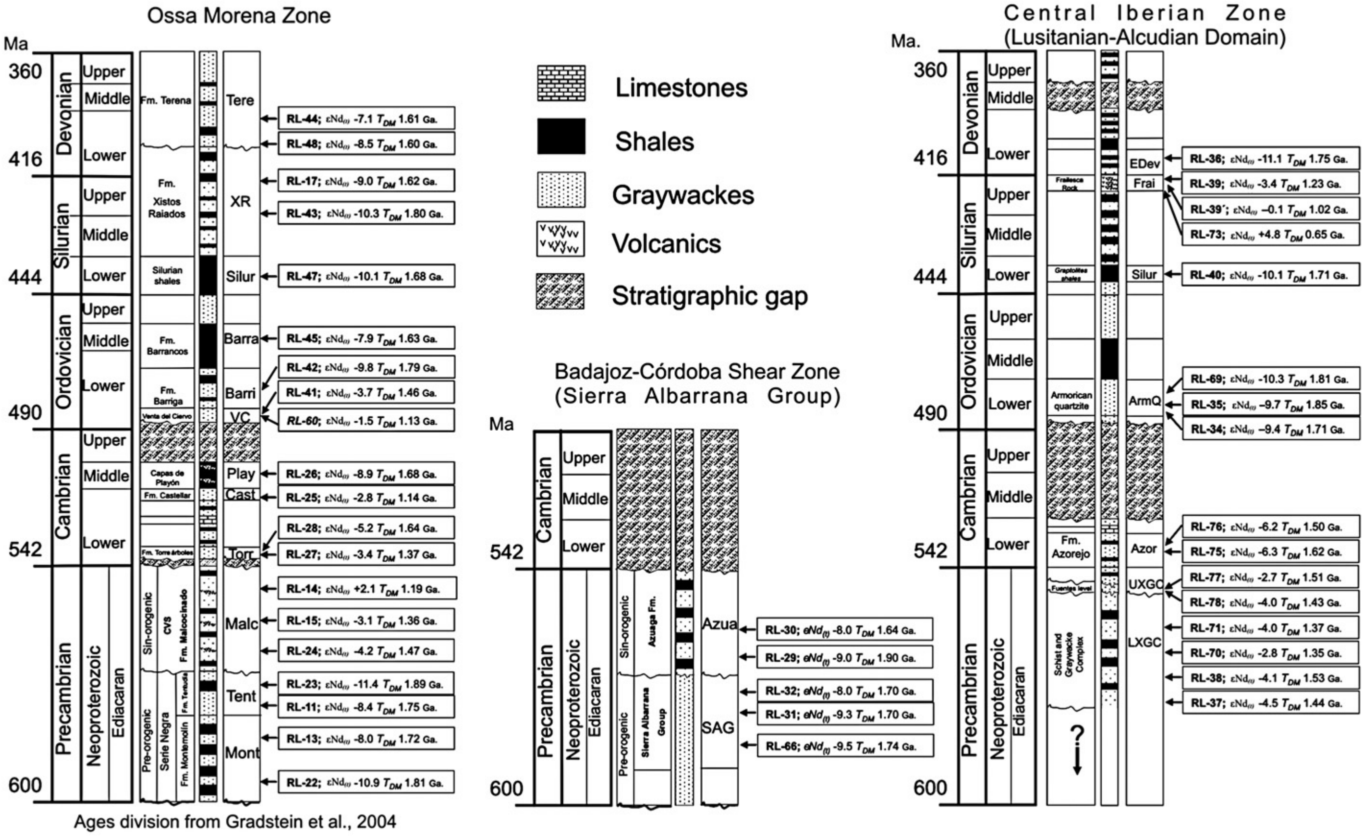

Fig. 2. Synthetic tectonostratigraphic columns of the Ossa Morena Zone (*left*), Sierra Albarrana Domain (Badajoz–Córdoba Shear Zone) (*centre*) and Central Iberian Zone (*Lusitanian– Alcudian Domain*) (*right*) showing the stratigraphic location of the samples and their corresponding $\varepsilon Nd_{(t)}$ and T_{DM} values. *Legend: Ossa Morena Zone = Mont: Montemolín Formation, Tent: Tentudía Formation, Malc: Malcocinado Formation, Torr: Torreárboles Formation, Cast: Castellar Formation, Play: Playón Beds, VC: Venta del Ciervo quartzite, Barri: Barriga Formation, Barra: Barrancos Formation, Silur: Silurian shales, XR: Xistos Raiados Formation, Tere: Terena Formation; Badajoz–Córdoba Shear Zone = SAG: Sierra Albarrana Group, Azua: Azuaga Formation; Central Iberian Zone = LCXG: Lower Schist and Graywacke Complex sequence, UCXG: Upper Schist and Graywacke Complex sequence, Azor: Azorejo Formation, ArmQ: Armorican quartzite, Silur: Silurian shales, Frai: Frailesca Rock, EDev: Early Devonian.*

490 Ma (i.e. the Ollo de Sapo rocks; Hernández Sampelayo, 1922; Lotze, 1945; Parga Pondal et al., 1964; Gebauer, 1993; Valverde Vaquero and Dunning, 1997, 2000; Fernández-Suárez et al., 2000b; Murphy et al., this volume).

Common features in both the OMZ and CIZ are: i) initial trans- gression (Lower Detrital Sequence) overlain by ii) an Early Cambrian carbonate platform which collapsed and was succeeded by to iii) an Upper Detrital sequence associated with volcanic activity and horst and graben formation, spanning from the Early to Middle Cambrian (Liñán, 1978; Liñán and Perejón, 1981; Liñán and Quesada, 1990; Liñán and Gámez-Vintaned, 1993; Sánchez García et al., 2003). A sedimen- tary hiatus, generally between the Middle and Late Cambrian, is thought to reflect thermal expansion, tilting, uplift and erosion during the main event of rift-related igneous activity (Sánchez García et al., 2003, 2008-this volume; Quesada et al., 2006).

In the intervening Badajoz–Córdoba Shear Zone, the only evidence of this the rifting event and Rheic Ocean development is recorded by intrusion of a bimodal set of c. 490–470 Ma plutons (Priem et al., 1970; Lancelot et al., 1985; Oschner, 1993; Ordóñez, 1998). The dominance of the plutonic record is thought to reflect significant exhumation and erosion of cover sequences during Variscan sinistral transpression along the shear zone.

3.3. The Ordovician–Devonian record (passive margin stage)

A generalized transgression propagated across the OMZ and CIZ has been interpreted as a break-up unconformity resulting from the thermal subsidence related to rifting initiated in the Cambrian (Quesada, 1987, 1991; Sánchez García et al., 2003, 2008-this volume), that progressed into the development of a significant tract of new oceanic lithosphere that reflects the onset of sea-floor spreading and the birth of the Rheic Ocean (Sánchez García et al., 2003; Quesada et al., 2006). Both the OMZ and the CIZ record a diachronous rift-to-drift transition from con- tinental, through to open marine environments, with the transition being older in the OMZ than in the CIZ. The initial southernmost (in present day coordinates) transitional deposits in the OMZ is Tremadoc in age (e.g. Venta del Ciervo Quartzite; Gutiérrez Marco, 1982; Gutiérrez Marco et al., 1984; Robardet and Gutiérrez Marco, 2004; López-Guijarro et al., 2007) whereas in the southern part of the CIZ (Alcudia Anticline area), the transitional sequence was deposited during the Arenig (Armorican Quartzite; Gutiérrez Marco et al., 1990, 2002). This diachroneity suggests that the OMZ occupied a more outboard position than the CIZ along the Gondwanan margin at that time, an interpretation that is consistent with the subsequent evolution of the two zones, which are characterized by outer shelf sedimentation in the OMZ and more proximal, inner shelf deposits in the CIZ. In addition, the presence of the Palaeozoic oceanic sequences of the Pulo do Lobo Zone and the Beja- Acebuches Ophiolite (Munhá et al., 1986; Quesada et al., 1994; 2006) south of the OMZ (Fig. 1) supports the notion that the actual SW Iberia could have been the thinned outer margin of Gondwana during the Palaeozoic (Quesada, 1987, 1991, 2006).

The OMZ and CIZ also both characterized by give age range pre- dominantly clastic sequences, interpreted as a passive margin suc- cession, that include an enigmatic Late Ordovician glaciomarine deposit, a similarity which suggests that these zones were juxtaposed to each other and to Gondwana during this time interval (Robardet, 1981; Robardet and Doré, 1988). Volcanic activity was almost non- existent in the OMZ from Late Ordovician to Early Devonian, but was

more voluminous in the southern CIZ, particularly near the Almadén mercury mine area, where Silurian–Early Devonian within-plate al- kaline basalts are genetically related to the world-class ore deposit (Hall et al., 1996, 1997; Hernández et al., 1999; Higueras et al., 2000,
2005).

4. Methods

Sm and Nd are light rare earth parent–daughter elements that behave coherently in the crust. As a result, intracrustal processes such as anatexis, fractionation, or regional metamorphism rarely affect the Sm/Nd ratio. Instead, variations in Sm/Nd ratio in crustal rocks are largely inherited from the depleted mantle, which preferentially re- tains samarium over neodymium (DePaolo and Wasserburg, 1976; DePaolo, 1981, 1988).

In order to better understand the geodynamic evolution and the provenance history of the CIZ and OMZ, we collected 47 representative samples of igneous and sedimentary rocks that accompanied each major event. The samples were selected from regions where the depositional age is constrained by field observations and mapping. Sm–Nd isotopic data for igneous rocks can constrain the composition, evolution and relative contributions of the mantle and crustal sources involved in their genesis (DePaolo and Wasserburg, 1976; DePaolo, 1981, 1988; Murphy and Nance, 2002) and therefore their possible geodynamic setting and the nature of the basement involved in the genesis of crustal melts. With this aim in mind, we have sampled both plutonic and volcanic, felsic, intermediate and mafic rocks exposed in the CIZ and OMZ zones.

Sm–Nd isotopic signature can constrain the provenance of low grade clastic rocks (e.g. Thorogood, 1990; Murphy et al., 1995; Murphy and Nance, 2002). Within the study area, samples exhibiting the lowest metamorphic grade were selected and the fine-grained facies were preferentially sampled (although for comparison the coarser grained facies within the same formations were also sampled) be- cause (i) finer-grained sediments provide a better representation of the average composition of their respective sources (references), and
(ii) Sm and Nd tend to accumulate in phyllosilicates.

All analytical procedures, including the mass spectrometer ana- lyses, were performed at the Laboratoire de Géologie, CNRS-Université Blaise Pascal, Clermont-Ferrand, France. Whole rock samples were powdered and spiked with a $^{149}Sm/^{150}Nd$ spike in the dissolution process. The separation was performed in three steps including:
(1) cation exchange columns with HCl chemistry, (2) Transuranides columns with HNO_3 chemistry and (3) chromatographic extraction columns for Lantanides (Le Fèvre and Pin, 2002, 2005; Pin et al., 1994). Sample decomposition was achieved by fusion with a $LiBO_2$ flux in an induction furnace at c. 1150 °C, as described by Le Fèvre and Pin (2005). Then, Sm and Nd isolation was carried out by cation exchange and extraction chromatography methods adapted from Pin and Santos Zalduegui (1997). Sm and Nd concentrations were measured by isotope dilution using a mixed $^{149}Sm/^{150}Nd$ tracer and thermal- ionization mass spectrometry (TIMS), allowing determining $^{147}Sm/^{144}Nd$ ratios with a precision of 0.2% (Le Fèvre and Pin, 2002). Sm was measured in the single collection mode on an automated VG54E mass spectrometer and Nd isotopic ratios were measured in the static multicollection mode with a Thermo Finnigan Triton TI instrument with normalization to $^{146}Nd/^{144}Nd$ = 0.7219. The JNdi-1 isotopic stan- dard measured during these analyses gave a $^{143}Nd/^{144}Nd$ = 0.512105 ± 6 (2 measurements), corresponding to a value of 0.511848 for the La Jolla standard (Tanaka et al., 2000).

The results are given in Table 1, where the protolith ages chosen for calculation of $\varepsilon Nd_{(t)}$ are based on zircon age determinations on rocks with the same stratigraphic position taken from the literature. The main Nd parameter is the $\varepsilon Nd_{(t)}$ which is very useful to compare coeval rocks because it is depending of the stratigraphic age of the rock. Where geochronological data were not available, these ages were estimated from stratigraphic and structural constraints. Geographic coordinates (GPS) were given for all samples and Nd model ages (T_{DM}) were calculated using the equation of DePaolo (1981).

4.1. Results from the Ediacaran rocks

4.1.1. Metasedimentary rocks

The Ediacaran metasedimentary samples collected in the OMZ belong to the Serie Negra (4 samples, RL-13 and RL-22 from the Montemolín succession, and RL-11 and RL-23 from the Tentudía Formation) (see Fig. 2 and Table 1). The Montemolín succession shows $\varepsilon Nd_{(t)}$ varying from − 8.0 to −10.9 and T_{DM} ages from 1.72 to
1.81 Ga. The Tentudía Formation yielded $\varepsilon Nd_{(t)}$ values ranging
from − 8.4 to − 11.4 and T_{DM} values between 1.75 and 1.89 Ga. Both Ediacaran sequences exhibit very similar negative $\varepsilon Nd_{(t)}$ values and T_{DM} ages significantly older than their depositional ages, pointing to a similar source that was mainly composed of old crustal rocks, with negligible contribution of juvenile material. Conversely, volcaniclas- tic metasediments of the overlying Malcocinado Formation (RL-14 and RL-15) near the top of the Ediacaran sequence show $\varepsilon Nd_{(t)}$ values ranging from + 2.1 to − 4.1 and T_{DM} ages vary from 1.19 to 1.47 Ga, (from the bottom to the top of the succession) (see Fig. 2 and Table 1). These data indicate a mixed provenance consisting of juvenile and old, recycled crustal components.

In the CIZ, 4 samples from the lower sequence in the Schist and Graywacke Complex were analysed (RL-37, RL-38, RL-70 and RL-71), yielding $\varepsilon Nd_{(t)}$ values from −2.8 to −4.5 and T_{DM} ages of 1.35 to
1.53 Ga. Two additional samples collected from the *Pusa Group* (RL-77
and RL-78) above the unconformable basal contact of the Upper Schist and Graywacke Complex sequence yield very similar $\varepsilon Nd_{(t)}$ values of − 2.7 and − 4.0, and T_{DM} ages of 1.43 and 1.51 Ga (see Fig. 2 and Table 1). Although the results obtained from the Ediacaran sam- ples of the southern CIZ differ considerably from those obtained from the OMZ's Serie Negra samples, they are comparable to the data from the Malcocinado Formation (Figs. 3 and 4). The data imply either the existence of a common source for the sediments in both zones in the latest Ediacaran or, that one was source to the other. In either case, the data imply geographic proximity in the Ediacaran.

We also analysed samples from metasedimentary formations oc- curring in the intervening Badajoz–Córdoba Shear Zone (Fig. 1).The Sierra Albarrana quartzites (RL-31 and RL-66) and associated fine- grained sediments, the Albariza micaschist (RL-32), yield negative $\varepsilon Nd_{(t)}$ values (ranging from − 8.0 to −9.5) and T_{DM} ages of 1.70 to
1.74 Ga. The graywackes and shales of the Azuaga Formation (RL-29
and RL-30, respectively) have $\varepsilon Nd_{(t)}$ values ranging from − 7.8 to − 9.0 and T_{DM} ages of 1.64 to 1.90 Ga (see Table 1 and Fig. 2 for location in the stratigraphic column). The data suggest that the dominant source of these formations is the Neoproterozoic sequences of the OMZ (Serie Negra) rather than the CIZ (Figs. 3 and 4).

4.1.2. Igneous rocks

Ediacaran igneous rocks in SW Iberia only occur in the Ossa Mo- rena Zone and in the Badajoz–Córdoba Shear Zone. They correspond to the calc-alkaline arc-related rocks of the Malcocinado Formation and coeval plutons (Sánchez Carretero et al., 1990; Bandrés et al., 2002, 2004). Sm–Nd data from the Córdoba andesites (Pin et al., 2002) yield positive $\varepsilon Nd_{(t)}$ values ranging from + 2.9 to + 7.6, and T_{DM} ages of 1.41 to c. 0.6 Ga. In this study we analysed two samples (RL-1 and RL-63) from the El Escribano pluton, which are a diorite and a granodiorite respectively. Although no radiometric age of this pluton is available, it intrudes Serie Negra rocks and is unconformably overlain by basal Cambrian conglomerates that contain cobbles de- rived from it, suggesting an Ediacaran age. $\varepsilon Nd_{(t)}$ values calculated for 550 Ma range from − 0.2 to − 0.1 and T_{DM} ages from 1.08 to 1.15 Ga. These values are much more negative and the T_{DM} is significantly older than the associated andesites (Pin et al., 2002), implying

Table 1
Sm–Nd analytical results of the samples used in this study (Legend of stratigraphic units as in Fig. 2)

Sample	Coordinates	Unit	Rock type	Sm (μg g^{-1})	Nd (μg g^{-1})	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	2S.E. (10^{-6})	$\varepsilon Nd_{(0)}$	Age (Ma)	$\varepsilon Nd_{(t)}$	T_{DM} (Ga)
Ossa Morena												
Igneous rocks												
RL-19	X=69,150; Y=4,264,800	Vmigm	Migmatite	0.44	2.24	0.1191	0.512199	10	−8.5	340	−5.2	1.35
RL-20	X=71,100; Y=4,279,250	Vmigm	Migmatite	2.43	10.7	0.1373	0.512194	8	−8.6	340	−6.1	1.65
RL-60	X=191,375; Y=4,210,600	VC	Tuffite	18.0	99.5	0.1095	0.512277	4	−7.0	489	−1.5	1.13
RL-10	X=212,875; Y=4,221,275	Cmigm	Granodiorite	6.31	33.1	0.1154	0.512192	5	−8.7	530	−3.2	1.32
RL-1	X=349,825; Y=4,225,100	Malc	Diorite	3.03	17.0	0.1082	0.512310	8	−6.4	550	−0.1	1.08
RL-2		Malc	Mafic dike	4.15	15.5	0.1618	0.512798	8	+3.2	550	+5.6	0.80
RL-63	X=365,610; Y=4,218,242	Malc	Granodiorite	3.06	15.6	0.1184	0.512334	12	−5.9	550	−0.2	1.15
Metasedimentary rocks												
RL-17	X=69,150; Y=4,264,800	XR	Shale	7.39	39.0	0.1144	0.511970	6	−13.0	380	−9.0	1.62
RL-44	X=163,800; Y=4,224,800	Tere	Conglomerate	4.51	21.8	0.1250	0.512090	8	−10.7	390	−7.1	1.61
RL-48	X=163,575; Y=4,223,150	Tere	Shale	6.87	36.0	0.1153	0.511993	6	−12.5	390	−8.5	1.60
RL-43	X=154,700; Y=4,227,925	XR	Shale	13.1	66.6	0.1187	0.511894	5	−14.5	415	−10.3	1.80
RL-47	X=159,950; Y=4,222,650	Silur	Shale	9.54	52.6	0.1096	0.511872	4	−14.9	430	−10.1	1.68
RL-45	X=163,775; Y=4,217,775	Barra	Shale	9.02	46.7	0.1167	0.511985	12	−12.7	470	−7.9	1.63
RL-42	X=191,110; Y=4,210,400	Barri	Shale	10.5	53.8	0.1175	0.511883	8	−14.7	480	−9.8	1.79
RL-41	X=191,375; Y=4,210,600	VC	Quartzite	1.57	7.27	0.1304	0.512233	5	−7.9	489	−3.7	1.46
RL-26	X=186,175; Y=4,263,725	Play	Shale	8.30	44.9	0.1118	0.511897	8	−14.4	510	−8.9	1.68
RL-25	X=195,025; Y=4,257,275	Cast	Quartzite	0.78	5.12	0.0929	0.512145	6	−9.7	520	−2.8	1.14
RL-27	X=222,725; Y=4,250,525	Torr	Conglomerate	6.36	32.3	0.1190	0.512190	7	−8.7	530	−3.4	1.37
RL-28		Torr	Shale	14.8	68.1	0.1316	0.512142	11	−9.6	530	−5.2	1.64
RL-14	X=210,387; Y=4,245,525	Malc	Shale	7.29	28.3	0.1558	0.512598	6	−0.7	550	+2.1	1.19
RL-15	X=211,575; Y=4,242,037	Malc	Shale	7.02	35.3	0.1202	0.512207	6	−8.4	550	−3.0	1.36
RL-24	X=210,762; Y=4,244,212	Malc	Graywacke	5.20	25.5	0.1231	0.512161	6	−9.3	550	−4.1	1.47
RL-23	X=206,712; Y=4,215,862	Tent	Graywacke	5.67	30.7	0.1117	0.511739	5	−17.5	560	−11.4	1.89
RL-11	X=206,925; Y=4,215,900	Tent	Shale	7.33	37.6	0.1178	0.511912	6	−14.1	570	−8.4	1.75
RL-13	X=212,675; Y=4,232,400	Mont	Shale	7.77	40.3	0.1167	0.511926	6	−13.8	570	−8.0	1.72
RL-22	X=212,800; Y=4,222,750	Mont	Graywacke	5.23	29.5	0.1070	0.511741	5	−17.5	570	−10.9	1.81
Badajoz–Córdoba Shear Zone												
Metasedimentary rocks												
RL-29	X=266,575; Y=4,237,225	Azua	Quartzite	8.02	38.2	0.1271	0.511926	6	−13.9	560	−9.0	1.90
RL-30	X=265,475; Y=4,239,875	Azua	Shale	6.06	32.9	0.1115	0.511926	11	−13.8	560	−7.8	1.64
RL-31	X=298,496; Y=4,235,029	SAG	Quartzite	1.99	11.4	0.1053	0.511817	5	−16	570	−9.3	1.70
RL-32	X=287,750; Y=4,217,650	SAG	Micaschist	8.25	43.6	0.1146	0.511916	7	−14.0	570	−8.0	1.70
RL-66	X=306,800; Y=4,233,350	SAG	Quartzite	1.48	8.16	0.1099	0.511828	5	−15.8	570	−9.5	1.74
Central Iberian Zone												
Igneous rocks												
RL-39	X=355,800; Y=4,294,425	Frai	Volc. breccia	7.51	40.3	0.1127	0.512232	7	−7.9	416	−3.4	1.23
RL-39'		Frai	Volc. breccia	9.89	50.7	0.1180	0.512417	7	−4.3	416	−0.1	1.02
RL-73		Frai	Mafic clast in RL-39	8.19	43.9	0.1128	0.512652	6	+0.3	416	+4.8	0.65
Metasedimentary rocks												
RL-36	X=340,675; Y=4,294,425	EDev	Quartzite	4.02	21.8	0.1116	0.511845	7	−15.5	400	−11.1	1.75
RL-40	X=343,075; Y=4,296,125	Silur	Shale	9.60	51.8	0.1119	0.511879	13	−14.8	430	−10.1	1.71
RL-34	X=336,725; Y=4,288,100	ArmQ	Quartzite	1.35	7.10	0.1145	0.511902	7	−14.3	470	−9.4	1.71
RL-35		ArmQ	Shale	15.3	74.9	0.1232	0.511913	13	−14.1	470	−9.7	1.85
RL-69		ArmQ	Shale	15.6	80.9	0.1166	0.511861	7	−15.1	470	−10.3	1.81
RL-75	X=331,625; Y=4,381,375	Azor	Limolite/shale	6.46	31.9	0.1224	0.512056	5	−11.3	530	−6.3	1.62
RL-76		Azor	Sandstone	2.72	14.7	0.1118	0.512025	5	−12	530	−6.2	1.50
RL-77	X=325,800; Y=4,392,775	UXGC	Graywacke	6.55	28.5	0.1387	0.512290	8	−6.7	545	−2.7	1.51
RL-78		UXGC	Shale	7.25	36.2	0.1210	0.512163	7	−9.2	545	−4.0	1.43
RL-37	X=379,850; Y=4,302,675	LXGC	Graywacke	7.61	39.5	0.1166	0.512118	6	−10.1	550	−4.5	1.44
RL-38	X=379,875; Y=4,302,725	LXGC	Shale	8.10	37.8	0.1295	0.512185	6	−8.8	550	−4.1	1.53
RL-70	X=336,527; Y=4,292,448	LXGC	Shale	8.34	41.6	0.1211	0.512222	5	−8.1	550	−2.8	1.35
RL-71		LXGC	Graywacke	7.41	39.9	0.1122	0.512126	5	−9.9	550	−4.0	1.37

T_{DM} and $\varepsilon Nd_{(t)}$ calculated following formulas described by DePaolo and Wasserburg (1976) and DePaolo (1981).

significant crustal contamination that is consistent with abundant Serie Negra xenoliths that are dispersed throughout the plutonic rocks. However, a mafic syn-plutonic dyke within the same pluton (RL-2) yields an $\varepsilon Nd_{(t)}$ of + 5.6 and a 0.8 T_{DM} age. This signature is much more primitive, and is within the range of the Córdoba andesites, rather than the associated granitoids.

4.2. Results from the Cambrian–Early Ordovician rift-related rocks

4.2.1. Metasedimentary rocks

The lowermost Cambrian sedimentary unit deposited in the OMZ is a fluvial to shallow-marine sequence (Torreárboles Formation, RL-27 and RL-28) that is part of the Lower Detrital Sequence (Liñán, 1978) (Fig. 2). It yields negative $\varepsilon Nd_{(t)}$ values in the range − 3.4 to − 5.2 and T_{DM} ages of 1.37 to 1.64 Ga, which are similar to those of the underlying Malcocinado Formation. A derivation from the local basement could account for this similarity. Higher up in the sequence, the Castellar quartzite (latest Early Cambrian) and the Middle Cambrian Playón Beds (Liñán and Perejón, 1981) (Fig. 2) yield $\varepsilon Nd_{(t)}$ values of −2.8 to −8.9 and T_{DM} ages of 1.14 to 1.68 Ga, respectively. These results, though slightly more negative and older than those from the basal Cambrian Torreárboles Formation, provide evidence for some input from juvenile mantle sources or contribution from a less evolved source, especially in the Castellar sample, in which case it may be sought in the coeval rift-related volcanic activity (Sánchez García et al., 2003).

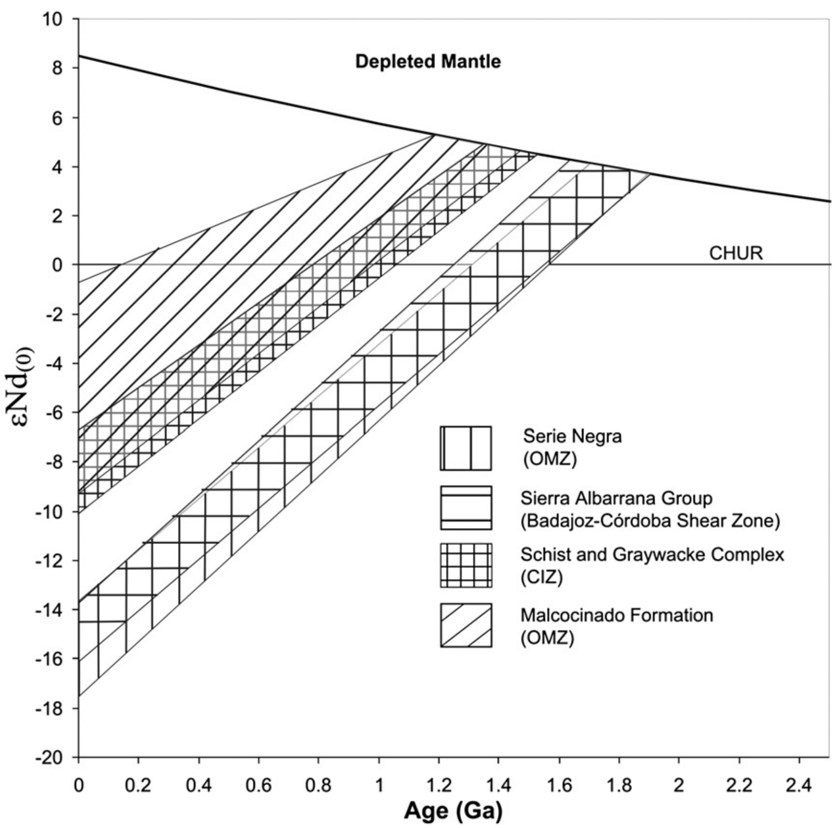

Fig. 3. $\varepsilon Nd_{(t)}$ vs. age diagram (DePaolo and Wasserburg, 1976; DePaolo, 1981) for the Ediacaran samples.

In the CIZ, the Early Cambrian Azorejo Formation (San José et al., 1974) was sampled in the southern Montes de Toledo area (Fig. 1). A limolite/shale alternation (RL-75) and a sandstone (RL-76) yielded $\varepsilon Nd_{(t)}$ values of − 6.3 and − 6.2 and T_{DM} ages of 1.62 and 1.50 Ga, respectively (see Fig. 2 for location). A faint inheritance from the underlying Schist and Graywacke Complex is perhaps suggested by these, still not very negative, $\varepsilon Nd_{(t)}$ values.

4.2.2. Igneous rocks

The influence of Cambrian–Early Ordovician magmatism on the Nd isotopic compositions of coeval sedimentary rocks is discernible by their less negative $\varepsilon Nd_{(t)}$ values (− 2.8 to −8.9, Table 1) and somewhat younger T_{DM} ages (1.14 to 1.68 Ga, Table 1), compared to the samples from the subsequent passive margin sequences (see below, Table 1 and Fig. 6). The Monesterio anatectic granodiorite (c. 530 Ma; Oschner, 1993; Ordóñez, 1998) (RL-10) has $\varepsilon Nd_{(t)}$ values of −3.2 and T_{DM} ages of 1.32 Ga, which indicate an important crustal consistent with the interpretation of the origin of the granite due to a granitoid derived by low-pressure melting of the Ediacaran Serie Negra (Eguiluz and Ábalos, 1992).

In comparison, migmatite neosomes produced by melting of Serie Negra protoliths (RL-19; $\varepsilon Nd_{(t)}$ = − 5.2, T_{DM} = 1.35 Ga) and Cambrian metasedimentary protoliths (RL-20; $\varepsilon Nd_{(t)}$ = −6.1, T_{DM} = 1.65 Ga) but in this case migmatization was developed during the Variscan orogeny in Early Carboniferous times (c. 340 Ma) (Pereira et al., 2006; Chichorro, 2006). The values obtained from these Variscan migmatites are very similar to the results from the c. 530 Ma Monesterio anatectic granitoid and those of the Early Cambrian metasediments in the OMZ (see above), respectively.

4.3. The Ordovician–Early Devonian passive margin

4.3.1. Metasedimentary rocks

In the OMZ, samples from the Tremadocian Barriga shales (RL-42) and the Venta del Ciervo quartzites (RL-41) (Gutiérrez Marco, 1982; Gutiérrez Marco et al., 1984, 2002; Robardet et al., 1998) (Fig. 2) have $\varepsilon Nd_{(t)}$ values of − 9.8 and − 3.7 and T_{DM} ages of 1.79 and 1.46 Ga, respectively. Higher up in the sequence (Fig. 2), the Arenig Barrancos shales (RL-45) (Oliveira et al., 1991) yield values of − 7.9 and 1.63 Ga. A Silurian carbon-rich pelite (RL-47), a Late Silurian–Early Devonian

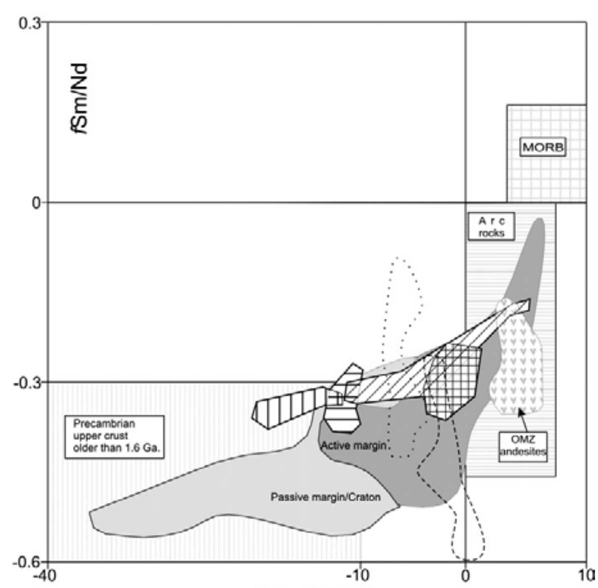

Fig. 4. *f*Sm/Nd vs. $\varepsilon Nd_{(t)}$ diagram (DePaolo and Wasserburg, 1976) showing the envelopes of the Ediacaran samples for each tectonosedimentary unit (legend as in Fig. 3). See text for explanation.

"Xistos Raiados" (Oliveira et al., 1991) sample RL-43, and two Early Devonian Terena Formation (Oliveira et al., 1991; Pereira et al., 2006) samples (RL-44, conglomerate and RL-48, shale), yield $\varepsilon Nd_{(t)}$ values ranging between −7.1 and −10.3, and T_{DM} ages between 1.61 and 1.80 Ga (Fig. 2).

Most $\varepsilon Nd_{(t)}$ values obtained from OMZ Ordovician–Early Devonian rocks are very negative (i.e. less than −7.1) and the corresponding T_{DM} ages are generally older than 1.5 Ga. These results are readily interpretable as evidence of the progressively increasing role of continental crust reworking as the main source of detritus supplied to the continental margin once the last event of mantle input into the crust was completed (the Cambrian–Early Ordovician mafic magmatism associated with the opening of the Rheic Ocean). The values become more negative up the stratigraphy until reach the Early Devonian samples where is recorded a subtle increasing in $\varepsilon Nd_{(t)}$ values, probably due to the first effects of Variscan orogeny in the actual SW Iberia. A mixture of Archaean and Proterozoic crustal elements plus juvenile Cadomian and Cambrian elements in the catchments areas could account for these results. The only exception occurs within the Tremadoc Venta del Ciervo quartzites (Figs. 2 and 4), which has much less negative $\varepsilon Nd_{(t)}$ and younger T_{DM} age. However, this anomalous analysis may be attributed to contamination related to minor juvenile volcanic input (Fig. 5), which is consistent with the presence of volcaniclastic interbeds (K-bentonites, see below).

In the CIZ, samples from the Arenig Armorican quartzite (Gutiérrez Marco et al., 2002) (sample RL-34) and interbedded shales (RL-35 and RL-69) yield $\varepsilon Nd_{(t)}$ values of −9.4 to −10.3 and T_{DM} ages from 1.71 to 1.85 Ga (Fig. 2). Also, a Silurian graptolite-rich shale (RL-40) and an Early Devonian quartzite (Fig. 2; Robardet and Gutiérrez Marco, 2002) gave, respectively, $\varepsilon Nd_{(t)}$values of −10.1 and −11.1, and T_{DM} ages of 1.71 Ga and 1.75 Ga. These results are indistinguishable from those of coeval sequences in the OMZ (Fig. 4). We interpret this similarity to indicate that both zones belonged to the same (passive) continental margin, or at least were supplied from the same sources.

4.3.2. Igneous rocks

Magmatic activity during this passive margin event was minor in the OMZ and CIZ zones. In the OMZ, some cm-thick rhyolitic tuff layers (K-bentonites) are interbedded with the Tremadoc Venta del Ciervo quartzite (Gutiérrez Marco, 1982; López-Guijarro et al., 2007), a few metres above the basal unconformable contact of the Ordovician sequence above the Cambrian rift-related sequence. A sample (RL-60; Fig. 2) yields an $\varepsilon Nd_{(t)}$ value of −1.5 and T_{DM} age of 1.13 Ga. These results suggest a mixture of recycled old crust components and a significantly less evolved source. Despite its location within the platformal passive margin, these results may reflect the influence of residual rift-related igneous activity, which according to Sánchez García et al. (2003, 2008-this volume) propagated diachronously towards the north- east (present coordinates) across the Iberian margin of Gondwana. In the southern CIZ, an important igneous event in the vicinity of Almadén (Ciudad Real) produced alkalic basalts (Higueras et al., 2000). We analysed a Silurian volcanic breccia (*Frailesca Rock*) which contains ultramafic and crustal fragments in an extremely altered (carbona- tized) matrix, (Hernández et al., 1999; Higueras et al., 2005). Sm–Nd isotopic analyses yield values of −3.4 to −0.1 for the $\varepsilon Nd_{(t)}$ and 1.02 to 1.23 Ga for the T_{DM} ages, which are interpreted to reflect significant contamination by upper crustal components as is implied by the abundant presence of quartzite and other metasedimentary clasts in the breccia. We also analysed a mafic fragment in this rock (RL-73) that gave an $\varepsilon Nd_{(t)}$ value of +4.8 and a T_{DM} age of 0.65 Ga, consistent with derivation of these mafic igneous rock in the underlying mantle.

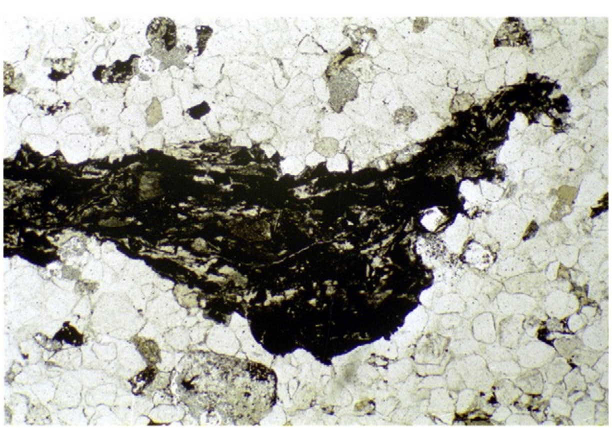

Fig. 5. Early Ordovician quartzite at Venta del Ciervo (RL-41). Detail of a vesicular glassy fragment of volcanic origin (NP, magnification: ×5).

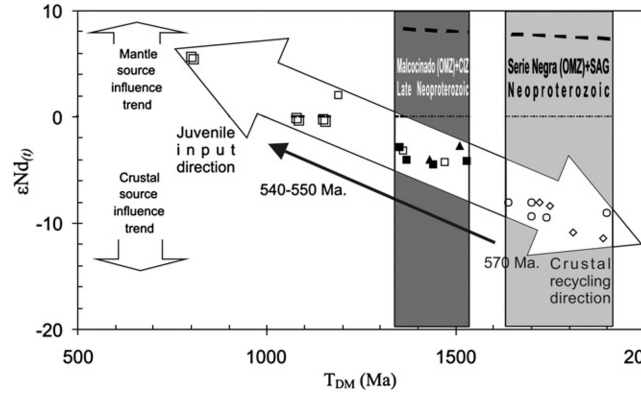

Fig. 6. T_{DM} vs. $\varepsilon Nd_{(t)}$ diagram as indicator of source rock type of the Ediacaran samples of CIZ, Badajoz–Córdoba Shear Zone and OMZ. Wide open arrows show the effect of syn-depositional mixing of old crustal and juvenile mantle components. *Legend*: OMZ samples represented by empty symbols (rhombs: Serie Negra; squares: Malcocinado Formation; double squares: Escribano pluton; circles: Sierra Albarrana Group); CIZ samples represented by black-filled symbols (squares: Lower Schist and Graywacke Complex; triangles: Upper Schist and Graywacke Complex). Two groups of rocks become evident: i) defined by the pre-orogenic OMZ Serie Negra and the Sierra Albarrana Domain samples (light gray shading), with little or no juvenile input; and
ii) defined by the OMZ Malcocinado Formation and the CIZ Schist and Graywacke Complex samples (dark gray shading), the latter with a higher juvenile input. See text for explanation.

5. Discussion: geologic significance of the Nd isotopic data

A first order finding of our Nd isotope study is that no significant differences exist in the Sm–Nd isotopic characteristics of the two zones suggesting that they shared the same sources at least from the latest Ediacaran throughout the Palaeozoic (Table 1, Figs. 3, 6 and 7). These data suggest that the OMZ and the CIZ have been welded together, or have remained in close geographic proximity, since the Ediacaran and that the OMZ belonged to the same continental margin of Gondwana as the rest of the Iberian Autochthon throughout the Palaeozoic (Quesada, 1991; Martínez Catalán et al., 1997; Robardet, 2003; Martínez Catalán et al., 2004, 2007).

Most metasedimentary samples yield very negative $\varepsilon Nd_{(t)}$ values and T_{DM} ages that are significantly older than their respective depositional ages, both parameters indicating a dominant component of ancient continental crust and with relatively minor input from juvenile sources. The exceptions to these generalizations coincide with two stages of igneous activity in the OMZ: i) the Late Ediacaran, arc-related Malcocinado Formation and coeval plutons, and ii) the Cambrian–Early Ordovician rifting. Metasedimentary rocks cor- responding with these two stages yield much less negative $\varepsilon Nd_{(t)}$ values and younger T_{DM} ages, suggesting mixing of the old crust components with juvenile mantle or less evolved crustal components. Significantly, coeval metasedimentary samples in the southern CIZ show the same trends, especially during the Late Ediacaran arc stage in

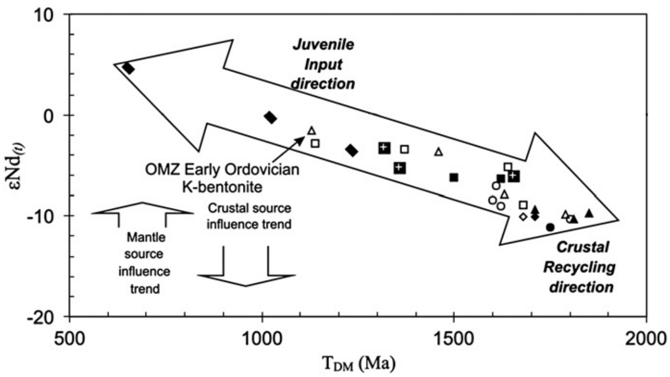

Fig. 7. T_{DM} vs. $\varepsilon Nd_{(t)}$ diagram as an indicator of source rocks of the Palaeozoic samples of the CIZ and OMZ. Wide open arrows show the effect of syn-depositional mixing of old crustal and juvenile mantle components. *Legend*: empty symbols correspond to the OMZ samples and black-filled symbols to the CIZ (squares: Cambrian, triangles: Ordovician, rhombs: Silurian and circles: Early Devonian); igneous rocks are represented by: filled rectangles (Silurian Fralilesca breccia–CIZ), white cross in black squares (OMZ migmatites). See text for explanation.

the OMZ (Figs. 3, 4 and 7), despite the lack of significant igneous activity in the CIZ in either of the two stages. We interpret this sim- ilarity, together with the presence of black chert cobbles of probable Serie Negra provenance (Pieren Pidal, 2000), as evidence for recycling of the OMZ arc sequences into the Central Iberian Zone during the Ediacaran. The Cambrian metasedimentary rocks in the CIZ contain slightly more negative $\varepsilon Nd_{(t)}$ and older T_{DM} than coeval metasedi- mentary rocks in the OMZ (Fig. 6). In this case we envisage a significant local contribution from the underlying Schist and Graywacke Complex during the Early Palaeozoic, which became proportionately less significant with time (Table 1, Fig. 6).

The pre-Cadomian Serie Negra sequences of the Ossa Morena Zone are characterized by very negative $\varepsilon Nd_{(t)}$ (− 8.0/− 11.4) and T_{DM} ages older than 1.7 Ga, indicating a dominant component of recycled old continental crust clasts in their origin, with a negligible juvenile input. These results are consistent with the mature character of the sand- stones and shallow water sedimentary structures reported by Quesada (1990a,b, 1997) in the lower Montemolín succession (Eguiluz, 1987). However, the low $\varepsilon Nd_{(t)}$ values occur in the volcaniclastic graywackes in the overlying turbiditic Tentudía Formation (Eguiluz, 1987) and the fact that both are overlain/intruded by the subduction-related arc volcanic rocks (Malcocinado Formation) and coeval plutons. This interpretation is consistent with the presence of an important Palaeoproterozoic (and older) detrital zircon population in the upper Serie Negra's Tentudía Formation (Schäfer et al., 1993; Fernández-Suárez et al., 2002b).

The $\varepsilon Nd_{(t)}$ compositions of the OMZ and CIZ also provide constraints on the isotopic characteristics of the crustal and mantle sources. The slightly negative $\varepsilon Nd_{(t)}$ values from arc-related Ediacaran igneous rocks in the OMZ (Escribano pluton, samples RL-1: diorite and RL-63: granodiorite) further support a dominant component of recycled old continental crust for the OMZ zone, as they show crustal contamination of the predominantly juvenile component (e.g. sample RL-2) and the Córdoba andesites (see Pin et al., 2002). Contamination by old continental crust is also demonstrated by inheritance of Palaeoproterozoic and minor Archaean zircon populations in igneous rocks of all ages intruded/extruded in the OMZ and in the Badajoz– Córdoba Shear Zone (Schäfer, 1990; Oschner, 1993; Ordóñez, 1998; Pereira et al., 2006; Chichorro, 2006; López-Guijarro et al., 2007).

The $\varepsilon Nd_{(t)}$ compositions of the Sierra Albarrana metasedimentary rocks are indistinguishable from those of the Serie Negra samples in the OMZ (Figs. 3, 4 and 7), suggesting derivation from isotopically indistinguishable sources. εNd envelopes for the Ediacaran samples on a *f*Sm/Nd vs. $\varepsilon Nd_{(t)}$ diagram (DePaolo and Wasserburg, 1976). Archaean–Palaeoproterozoic upper crustal rocks (McLennan and Hemming 1992; McLennan et al., 1993) and for arc volcanics and MORB are shown as well as the fields for recent sediments from passive and active margins. For comparative purposes, the envelopes of the Córdoba andesites (Pin et al., 2002; a correlative of the Malcocinado and the Lower and Upper Schist and Graywacke Complex rocks of the CIZ, Tassinari et al., 1996; Ugidos et al., 1997, 2003) are also included. From this diagram (Fig. 4) the following interpretations may be drawn:

i) The bulk of our Serie Negra (OMZ) and Sierra Albarrana meta-sedimentary rocks has a clear linkage with Archaean and/or Palaeoproterozoic continental crust sources and passive margin depositional environments.

ii) The Malcocinado Formation metasedimentary rocks, volcani- clastic metasediments, volcanic and associated plutonic rocks show a wide range in $\varepsilon Nd_{(t)}$ and a nearly linear, very narrow, *f*Sm/Nd array, which lies between the field defined by the Serie Negra and Sierra Albarrana metasediments and the field defined by the arc-related Córdoba andesites (Pin et al., 2002). The linear array extends across the fields for passive margin sediments, through that of active margin sediments into the field of arc volcanic rocks (McLennan and Hemming, 1992; McLennan et al., 1993). A possible implication is that the Nd isotopic composition of the Malcocinado Formation might reflect various degrees of mixing between the Serie Negra plus Sierra Albarrana metase- dimentary rocks (or coeval sediments derived from the same source) and the Córdoba andesites or their correlatives.

iii) The Upper and Lower Schist and Graywacke Complex in the southern CIZ plot in a very restricted field that is very similar to the intermediate part the Malcocinado Formation field. They also plot within the field for the active margin sediments. The data are indistinguishable from those of the Lower Schist and Graywacke Complex (dashed-line envelope in Fig. 4 after Ugidos et al., 1997, 2003) and are broadly similar to the field defined by the Ugidos et al. (1997, 2003) for the Upper Schist and Gray- wacke Complex for samples collected further north within the CIZ (although our samples are more juvenile, possibly due to a greater contribution from the Córdoba andesites). Their results show in both cases a strong dispersion parallel to the *Y*-axis (*f*Sm/Nd), which may reflect the range in Sm/Nd compo- sitions in the metasedimentary rocks. In general, however, the $\varepsilon Nd_{(t)}$ values are similar to our CIZ samples. Together with geological evidence referred to above, the whole set of data for Ediacaran metasedimentary rocks for the CIZ suggest that either the Schist and Graywacke Complex are derived from similar sources to those feeding the Malcocinado Formation, or the OMZ as a whole was the source of the Schist and Graywacke Complex. We favour this latter interpretation as the more negative $\varepsilon Nd_{(t)}$ values of Ugidos et al. (1997, 2003) from the Lower to the Upper sequences (closer to the OMZ Serie Negra field) is not detected in our samples despite being located much closer to the OMZ. This interpretation implies an age migration of the Upper and Lower Schist and Graywacke Complex sequences from the southern to the northern CIZ domains, which would require progressive erosion of the OMZ arc and exposure of the underlying Serie Negra rocks.

iv) The data suggest that the OMZ and the CIZ were close to one another by the time of the deposition of the Schist and Gray- wacke Complex in the CIZ (López-Guijarro, 2006).

On an $\varepsilon Nd_{(t)}$ vs. T_{DM} diagram (Fig. 7), the Ediacarin metasedimentary samples split into two groups: one including the Serie Negra and Sierra Albarrana samples and another one, where the Malcoci- nado Formation (OMZ) and Schist and Graywacke Complex samples concentrate together. Coeval igneous rocks define a linear array which we interpret as a mixing line between a continuous supply of old continental crust components and a juvenile component added during the period of arc growth in the OMZ. The linear array plus the superposition of the results from the Malcocinado Formation (OMZ) and Schist and Graywacke Complex samples support the interpretation of the OMZ as source area to the southern CIZ during deposition the Ediacaran.

The data for the Ediacaran rocks imply that the OMZ arc had a continental basement. This basement is exposed in SW Iberia, but it may be similar to the c. 2.0 Ga Icart gneiss, which is exposed in the Armorican Massif of NW France (Strachan et al., 1989, 1990, 1996, 2007; Samson and D'Lemos, 1998; Samson et al., 2003, 2005), which is not far from adjacent to correlatives of the Serie Negra (Lamballe Formation; Chantraine et al., 1988; Dabard and Loi, 1998; Dabard, 2000). In fact, among the wholesale of Neoproterozoic magmatic arcs that formed at the periphery of Gondwana during the break-up of Rodinia, the Armorican Massif and the OMZ are the most representa- tive examples of so-called Cadomian-type arcs, built on ancient (Palaeoproterozoic) continental crust, as opposed to the largely more abundant Avalonian type, which developed upon more juvenile (Neoproterozoic) crust (Nance et al., in press).

All the Ediacaran sequences in the OMZ and CIZ were affected by variably penetrative deformation prior to deposition of basal Cam- brian strata (Cadomian orogeny) (Ortega Gironés and González Lodeiro, 1986; Quesada, 1990a,b, 1997; Pieren Pidal, 2000), consistent with the Sm–Nd isotope data suggesting a proximal relationship at that time. Evaluation of the relationship between OMZ and CIZ prior to the Ediacarin is hindered by the absence of older basement exposures in the CIZ. However, Fernández-Suárez et al. (2000a, 2002a,b) and Gutiérrez Alonso et al. (2003) have documented two predominant populations of detrital zircons in the Ediacaran strata of the northern Iberian Massif (Cantabrian Zone): one, c. 1.0–1.2 Ga (Grenvillian s.l.) and, another, c. 0.65–0.55 Ga (typically Cadomian), suggesting an Amazonian affinity for this zone. In the OMZ's Serie Negra these authors (see also Schäfer et al., 1993), found no Grenvillian-age zircons, but documented a population with c. 2.0–2.2 Ga ages (attributed to derivation from the West African craton) in addition to a Cadomian population. Similar results were obtained by Fernán- dez-Suárez et al. (2002b) and Samson et al. (2005) in rocks correlative with the Serie Negra in Brittany. They concluded that the northern Iberian Massif lay adjacent to Amazonia whereas the OMZ must have lay close to West Africa by the Neoproterozoic (Murphy and Nance, 1989, 1991, 2002; Nance and Murphy, 1996; Nance et al., in press) and that their juxtaposition by c. 540 Ma was achieved by strike-slip processes (Fernández-Suárez et al., 2002a,b). This scenario is con- sistent with our data and with other geological evidence, such as a common tectonostratigraphic Palaeozoic history and the presence of typical Serie Negra black chert cobbles in the Schist and Graywacke Complex in the southern CIZ, suggesting the two zones must have been juxtaposed before deposition of the Schist and Graywacke Complex in the Late Ediacaran. We favour the hypothesis that their juxtaposition was achieved during their Cadomian deformation, which we envisage as the result of the accretion of the OMZ con- tinental arc to the CIZ (Quesada 1990a,b, 1997). Accretion governed by strike-slip processes is a possibility, as no clear ophiolitic suite is preserved in between, subsequent strong overprinting during Early Palaeozoic rifting and the Variscan orogeny obscures interpretations of its Ediacarin history. In this model, the final stages of accretion involved a component of thrusting of the OMZ onto the southern CIZ, and development of a foreland basin in response to the imposed load. The Schist and Graywacke Complex may represent the flysch infilling the foreland basin, whose depocenter migrated ahead of the north- ward (present coordinates) propagating orogen. The uplifted OMZ hanging wall would have supplied the detritus. This model does not apply to the North Iberia Ediacaran sequences as the presence of c. 1.0–1.2 Ga detrital zircons indicates either a different, or an addi- tional source, of detrital sediments.

With the exception of juvenile inputs during the Cambrian–Early Ordovician and the local Silurian rifting events in the CIZ, the Palaeozoic data indicate a dominant contribution from old crustal components in the two zones, typical as of passive margin sedi- mentary sequences (Quesada, 1987, 1991, 2006). On an $\varepsilon Nd_{(t)}$ vs. T_{DM} diagram (Fig. 6), no distinction between OMZ and CIZ analyses is apparent, suggesting derivation from the same or very similar sources. Like the Ediacaran samples (Fig. 7), the data show a linear array when the igneous rocks are considered (Fig. 6), which we interpret as evidence for mixing of continental and juvenile mantle sources. However, in contrast with the Ediacaran samples, the Palaeozoic data show a range in composition that shifts progressively with time towards a field of minimal juvenile contribution, which have similar values like samples from the Ediacaran Serie Negra and Sierra Albarrana sequences (see Figs. 6 and 7 for comparison). This implies that the same continental sources that supplied the OMZ in the Neoproterozoic may have supplied detrital sediments to both zones during the Palaeozoic.

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